DEVELOPMENTS IN MODERN AERONAUTICS

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Aeronautics performs two important functions in our present civilization exemplified by the parallel development of civil and military aviation. In civil life the airplane has proved to be a versatile and useful tool to perform many tasks. Among these are such special applications as aerial surveying, insect extermination, and air-sea rescue, to mention only a few, but the most important use is the transport of passengers, mail, express, and freight. The airlines have become not only supplementary to but also competitive with other transportation systems. Of perhaps greater significance than the performance of these useful services is the effect of air transport on our present national cultures. By removing the natural barriers of space and time the airplane is exerting a strong social influence. Its ability to travel at high speed in the third dimension over oceans and mountains and over political frontiers has multiplied contacts between peoples otherwise isolated, and introduced them not only to new customs and traditions but also extended to them new knowledge and new skills. The removal of barriers and promotion of mutual understanding between nations is one of the important effects of modern aeronautics.

Military uses of the airplane for offensive and defensive warfare have exercised a predominant influence on aeronautical development. This is certainly in evidence today in the large effort being expended to attain the highest possible performance and military effectiveness of aircraft and missiles. It is hoped that the military airplane, like the revolver and club of the policeman, will be an instrument of peace in the hands of peace-loving people and so far air power seems to have been effective in discouraging large-scale aggression. As measured by any index, the military function of the airplane furnishes the greatest incentive to aeronautical progress in our time.

Developments in modern aeronautics rest on recent technical accomplishments reached in the struggle to design and construct a vehicle which will move more rapidly from one place to another over the surface of the earth, climb faster to higher altitudes, and carry larger loads to greater distances, all as economically as possible as measured by initial and operating costs. The incentive to increase performance is greatest in military aircraft, and the cost considerations are given less weight. Hence military developments lead the way in performance and place emphasis on advancing the frontiers of science and engineering. Civil applications follow somewhat later with primary emphasis on cost, safety, and reliability. The time scale is hard to predict, but I have no doubt that most of the developments now applicable only to military aircraft will eventually be found in civil aircraft.

On August 27, 1939, the Germans made aviation history by flying a Heinkel 178 airplane powered by a new type of powerplant, a turbojet engine. On May 14, 1941, the British independently made more history with the flight of a jet-propelled Gloster airplane. The Russians have not yet disclosed the date when they first took to the skies jet propelled; though we can be sure that some day priority will be claimed regardless of the facts.

In London during the last war the inhabitants became acquainted with the V-2 rocket, powered by another new type of powerplant, the liquid fuel rocket. This weapon traveled several times faster than sound, emitting no warning sound in advance. Survivors saw the explosion and only afterward heard the noise arising at successive points along the path in reverse order, much like a phonograph record played backwards. Liquid fuel rockets powered the X-1 airplane which on October 14, 1947, attained sustained horizontal flight at supersonic speed.

The jet and rocket powerplants give a great deal of power per pound of weight and per unit frontal area and have the desirable characteristic that the power increases with the speed. Jet engines are still relatively young and their potential development has only begun. Thrust has steadily increased as larger and larger engines were developed and specific fuel consumption has decreased as higher compression ratios and temperatures have been made practical by developments in design and materials. Development of the afterburner has made possible the use of much larger thrust from an engine of given size. These new powerplants make possible sustained supersonic flight.

As already noted sustained horizontal flight at supersonic speeds was accomplished in a special research airplane in 1947. This performance was the culmination of a cooperative program begun in the United States in 1944 by the NACA, the Air Force, the Navy, and several airplane manufacturers to meet the need for aerodynamic information at speeds near the speed of sound. The program includes several airplanes with a variety of wing sections and plan forms and with both turbojet and rocket propulsion. The high speeds and altitudes reached by these airplanes (officially announced as more than 1200 miles per hour and approximately 80,000 feet) are not the most important results, since the airplanes have limited endurance. The X-1, X-2, and D558 II are carried aloft by a mother airplane to make most effective use of the limited fuel supply. The significant results are the quantitative data obtained on drag, stability, trim changes, air loads, etc. An unexpected result has been the psychological effect of the research airplane flights in dispelling fear of the problems of transonic and supersonic flight. Familiarity with the problems serves as a stimulus to ingenious men to find methods of overcoming the difficulties.

It is well known to you that some tactical military aircraft with full military equipment are able to reach supersonic speed in dives, for the bang of the shock waves reaching the ground from airplanes attaining supersonic speed is a common occurrence near military airfields and aircraft factories. For security reasons I can not discuss the exact technical position but it is clear that the accomplishment of the research airplanes will eventually be duplicated by military aircraft. And if the past is a guide to the future and we look sufficiently far ahead, supersonic speeds may be attained in the civil use of aircraft. Those who are skeptical should be referred to the interesting group of statements published by the Aircraft Industries Association under the colorful heading "Quotes that Failed." These are collections of forecasts, some by very famous men, which turned out to be wrong. I do not think, however, that airlines should delay their purchases of new equipment until supersonic speeds are offered them.

A third area of technical accomplishment in military aircraft and missile development is automatic stabilization and control. Automatic pilots have been in use for a long time on both military and civil aircraft for the purpose of maintaining a preset course and altitude. Some publicity has been given to the use of automatic devices to damp undesired oscillations and to improve flying qualities in general. The coupling of blind landing systems and bombing systems to the automatic pilot has been disclosed. Some brief discussions have been given of missile guidance systems. Here is a relatively new art being advanced very rapidly for military purposes, with ultimate benefit to civil aviation.

As the performance of airplanes increases, new problems are created by the unchanging performance of man himself. His body must be protected from the thin atmosphere at high altitudes by pressurized suits or preferably by pressurized cabins. He must be provided with and environment in which the temperature and humidity are within tolerable limits. The noise level that surrounds him must not get too high or else his efficiency is impaired.

As the speeds approach and exceed the speed of sound, man's physical strength is insufficient to operate the controls and must be supplemented by mechanical or electrical power. His ability to react to sudden unforeseen crises becomes inadequate in many cases, and this function must be turned over to an automatic device whose reaction time can be made very short. His vision is not adequate to pick up approaching aircraft and must be supplemented by electronic means. Here is a fourth area of technical accomplishment underlying the present military development of the airplane.

These technical accomplishments are the culmination of a type of human activity which is the key to progress. Have you ever stopped to consider that every accomplishment must have been preceded by the vision of that accomplishment in the mind of some man or woman?

The speedy and comfortable airliner in which the representatives of all nations of the world may travel to their assembly hall within 50 hours existed first in that invisible world of the mind. The extensive network of airlines was first conceived, and only later became a reality. The process continues today. Men are dreaming dreams, stirred by longings for still greater accomplishments. Dreams sharpen to vision which points to the pathway toward realization. This is the fruit of the creative genius of man, that inheritance which sets him apart from other animals, and by which he can completely change his environment.

The first controlled human flight of an airplane was made by Orville Wright on December 17, 1903, at Kitty Hawk, North Carolina. The Wright airplane was powered by an internal combustion engine of about twelve horsepower. This first flight for a distance of 120 feet in twelve seconds now seems quite unimpressive. But it had been envisioned and seriously sought for several hundred years.

Today it is very difficult to discover the designer of one of our modern airplanes. It is the product of a large organization of many specialists of many types, a team. No member of the team can comprehend the final product in all its detail. When you examine this modern aircraft you do indeed wonder how any one man could have invented or designed it. Of course no one man did or could. Its development rests on the contributions of many men in the past and of many men now living.

Yet in spite of the enormous differences in method I still maintain that the concepts must originate in the minds of men before there can be any physical accomplishment. Even the intensive organization of specialist skills must itself be envisioned by the mind of the aircraft or engine designer before the steps toward accomplishment can begin. Vision is still the first step.

Vision is guided nowadays not only by the experience and accomplishments of the past but by that specialized and somewhat artificial type of experience which we call scientific research. Modern aeronautical science seeks to know how air flows around bodies, what forces are exerted on bodies moving through the air, how materials and structures behave under load. Such knowledge is the secure foundation on which all engineering accomplishment in aeronautics rests. Theoretical research and experimental research, a cultivated and controlled type of experience, supply the sustenance to nourish a realizable vision.

The great successes of science have led to the incorrect conclusion on the part of many that any project which can be conceived can be accomplished at a relatively early date by supplying adequate funds and manpower. We have passed from a period in which accomplishments in aviation outran pessimistic prophecies to a period in which optimism is rampant. An interesting prophecy was made in 1924 by Huguenard, a French experimenter. Huguenard was one of a group of

French scientists who borrowed the compressed air plant of the Compressed Air Company of Paris, ordinarily used to supply air for a pneumatic system for transferring mail from one post office to another in the city of Paris. The air was borrowed to drive a 3-inch supersonic wind tunnel for testing models of artillery projectiles at supersonic speeds. Huguenard made the following prophecy: "Alone among all methods of transportation, aviation has shown, from its very beginning, an extraordinarily rapid increase in speed. From about 33 miles per hour in the first flights, we have progressed in 21 years to more than 270 miles per hour, the speed doubling regularly every five or six years. This is certainly not accidental. At each new performance, pessimistic calculators, accepting with more or less grace the results already obtained and arming themselves with formulas borrowed from other modes of locomotion, have somewhat advanced the limit they had previously set to the speed of aircraft, whereupon this new limit has been promptly exceeded. Since there is no indication of any change in the speed curve, we must logically expect aircraft to attain speeds of the order of 540 miles per hour within five or six years, that is in 1929 or 1930. The high velocity wind tunnel will doubtless be an important factor in solving the problem as to what new means of propulsion will be required."

Huguenard's only error was the use of a geometrical rather than an arithmetical progression. He assumed that the speed would double every six years. Actually until the advent of the jet engine the aircraft speed record increased more or less regularly at the rate of about 14 miles per hour per year and it required another 20 years rather than the predicted 5 or 6 to reach the predicted speed. Speeds of tactical military aircraft lag the speed record by a few years and the speeds of commercial aircraft lag by about 15 years.

There is much confusion in the public mind between dreamers, men of vision, and visionaries. The dreams of human flight began before recorded history, based on observation of the flight of birds and on belief in the control of Nature through magic. The magic flying carpet of the Arabian Nights is a means of aerial transportation whose motive power appears entirely supernatural to our generation, however it may have appealed to the originator of the tale many centuries ago. The modern teller of tales of space ships equipped with anti-gravity shields is perhaps a descendant of the ancient narrator. Only in the nineteenth century after the discovery of the steam engine and later the internal combustion engine did the dreams develop into vision which led to realization. Progress was made by men who conceived methods of accomplishing human flight which appeared feasible in the light of their past experience and the knowledge of other men's work accessible to them. They exhibited creative thought and were men of vision, attempting to fashion the materials and methods of their day to new purposes.

Those who ignore the state of scientific and engineering knowledge are mere visionaries.

The development of the V-2 rocket has greatly stimulated thoughts of much more radical developments, beginning with possible transport of passengers and freight for long distances over the earth's surface at speeds of several thousand miles per hour and the concomitant application to intercontinental warfare. From this it is but a step to consider vehicles which will leave the surface of the earth to become man-made satellites of the earth and a slight outreach of the mind to interplanetary travel, or, if that seems too great a step for you, to travel in space as far as the moon, at least.

At some point in this progression the visions are not realizable visions but mere dreams. Many competent people, in particular the designer of the V-2, feel that a satellite vehicle is feasible from a purely technical point of view, and I am inclined to agree that the technical problems are solvable with a large but finite amount of money. I must add that at present I believe that there are more important ways of spending the money and manpower.

Like the concepts of flight during the nineteenth century these concepts of space travel are the result of attempts of imaginative men to see how the technology of our day can be applied to the problems of interplanetary travel. Such attempts do not constitute a safe foundation for an engineering undertaking. The missing requirement is a broader basis of experience in the scientific and technological problems involved, and perhaps unanticipated scientific developments in apparently unrelated fields. I am reasonably sure that the accomplishment of travel to the moon will not occur in my lifetime and probably not in yours, although this goal will no doubt be eventually reached by the human race. It is not profitable, in my opinion, to devote large sums to design and construct prototype vehicles for space travel at this time, for the basic scientific and technical data are not yet in hand.

The foundation of continuing advance in aeronautics is organized research. Like the foundation of a building this important activity is not often in the public view. However, the adequacy of the research effort determines the quality of the aircraft. From the experience of NACA the quality of the aircraft to be manufactured four years from now depends on the research now being started in experimental facilities whose construction began four years ago. A variety of activities is included under the term "research", all aimed to learn how to make better aircraft. The immediate goals are varied. Looking toward the aircraft of the somewhat distant future it is required to conduct a type of research to which the adjectives "pure", "basic" or "fundamental" have been applied by various writers. The setting of practical goals has little value in this type of research, since the worker himself cannot foresee the possible applications or evaluate their true worth. The aim is to explore new fields and to search for understanding of the phenomena under study. However, it is possible and desirable to guide these studies into areas which are likely to bring productive results in a given technological field.

A great deal of the work of my own organization is in the field of applied research intended for application to aircraft and missiles now being designed. Here systematic surveys of limited technical fields prove useful and we have found considerable profit in programs intended to prepare an adequate foundation for some advanced technical development.

The aircraft and missiles already flying yield numerous research problems and provide more intimate contact between research worker and designer. A moderate amount of support of specific applications is beneficial but too much effort of this type inhibits rapid progress on more advanced developments.

The dependence of aircraft designers on an organized research program is one of the most striking developments in modern aeronautics, and the powerful effect of such a program in accelerating progress in aircraft performance is evident. Many of the difficult problems under study in aeronautical research laboratories today arise from the desire to develop fully supersonic aircraft of improved performance. A few of these will be briefly reviewed.

From the aerodynamic point of view the principal problems arise from the radical changes in the aerodynamic relationships at speeds faster than sound as compared with those prevailing at speeds slower than sound, and the necessity for any practical airplane to take off, land, and fly satisfactorialy in both the subsonic and the supersonic regions. In many cases shock waves, accompanied by separation of the flow from the surface, vary in position with changing speed, sometimes fluctuating violently and giving rise to buffeting of the airplane. There are changes in the angular trim of the airplane with speed in the transonic region as well as changes in stability. A major goal of research is the discovery of configurations which have the smallest changes in trim, control, and stability over the range of subsonic, transonic and supersonic speeds. Information is becoming available to permit the development of airplanes capable of further penetration of the transonic and low supersonic speed ranges with fewer operational limitations. The limited successes already realized have brought to light many detailed problems which can be solved by continued research. Tremendous improvements in the aerodynamic characteristics of aircraft configurations at transonic and supersonic speeds have already been made, including large drag reductions and improved stability and control. A striking feature of the results is the sensitivity to details of design which forecasts a necessity for much additional specific testing.

A continuing powerplant problem is that of performance at altitude. One of the first discoveries about jet engines in flight was that when the airplane reached a high altitude the fire in the engine often went out. This forced the pilot to come down to a very much lower altitude to restart his engine. This problem has been under constant study by NACA in facilities which permit duplicating the altitude operating conditions on the ground. As a result of research the progress has been good; today's jet engines can be operated dependably at altitudes more than twice as high as before this research program began.

Recent improvements in gas-turbine-engine performance through adoption of afterburners on turbojet engines for thrust augmentation have complicated the problem of engine control. The technical characteristics of jet engines require operation near the safe limits of speed and temperature. The control problem places an intolerable burden on the operator unless quick-acting, accurate, stable, and safe control systems are fitted to the engines. The solution of these problems is most effectively accomplished in equipment for operating the complete system under altitude conditions and by the use of analogue computers for rapid study of the effects of design changes.

In order to obtain high performance, the hot parts of jet engines are made of high-temperature alloys which contain alloying metals either not found in North America or in limited supply. A major trend in engine development is the reduction of strategic material content to permit large scale production. Research is in progress ranging from basic research on why materials behave as they do to substitute materials and to turbine blade cooling. Turbine blade cooling offers promise either of removing practically all of the strategic materials from the blades while retaining present performance or of substantially increasing output for applications for which the strategic materials can be allocated in sufficient quantity.

The design of safe structures for transonic and supersonic flight is a major current problem. The requirements of long-range, high-speed, high-altitude operations often result in a relatively flexible airplane structure. This gives rise to important mutual interactions between structural deflections and aerodynamic loads as well as to important transient dynamic loads in gusty air and on landing. Furthermore, the flexible structure may vibrate unduly or exhibit the catastrophic phenomenon of flutter. These phenomena may be studied by investigations of dynamically similar models as well as by more fundamental studies of the component aerodynamic and structural behavior under dynamic conditions. A second structural problem which will in time become the major problem limiting further gains in aircraft and missile performance is that of the distortion of the structure and changes in its strength arising from the heating of the skin of high-speed aircraft and missiles.

The effects of the flight environment on both man and machine give rise to many research problems. The environment of supersonic flight at high altitude is one of low ambient pressure, high temperature, high accelerations in maneuvers or gusty air, intense vibration, and high noise level. High altitude is required if supersonic flight is not to be extremely costly in fuel, but high-altitude flight introduces severe problems for the power plant. As the air density is reduced, a greater and greater volume of air must be forced through the engine to supply the necessary oxygen to burn the fuel. The problem of maintaining combustion has already been mentioned, but there is also the problem of obtaining a reasonably high efficiency of combustion even when flameout does not occur. Research workers are busily engaged on the environmental problems of other aircraft equipment. There is also progress in the determination of the physical properties of the air at high altitudes by means of sounding rockets and in reproducing this environment in the laboratory for studying the problems to be encountered in high-speed flight in the upper atmosphere at heights up to a few hundred miles.

Many of the environmental effects on man can be solved by supplying the occupants with a suitable environment which is independent of the space outside the aircraft. The most difficult problem is caused by acceleration, since no insulating material is known, nor is there any reason to believe that one exists. The supersonic speed itself causes no problem since man has no inherent sense of speed. Just as we do not perceive with our muscular sense the motion of rotation of the earth or the motion of the earth about the sun, we can not tell the difference between a speed of 100 miles per hour and 1000 miles per hour, if the atmosphere is smooth. An airplane flying in turbulent air is subjected to accelerations similar to those produced by irregularities in a rough highway when traveling by automobile at high speed. Supersonic aircraft in gusty air may be merely uncomfortable or they may be structurally unsafe. Buffeting from flow separation may also be quite uncomfortable to human occupants or dangerous to the structure.

This list of problems associated with the development of supersonic airplanescould be extended at length, but these are not the only important problems of aeronautical research. There are important areas of special concern to civil aviation such as noise, fire prevention, optimum deicing or ice prevention systems, and reliability of equipment. Thus considerable research is in progress on aircraft noise and data are available for predicting the noise levels to be expected under various circumstances for points both inside and outside the aircraft. Reasonable progress has been made in demonstrating reduction of noise in small light airplanes but it does not as yet seem feasible or safe to apply the same measures to large high-powered aircraft. With present knowledge the engineer can only inform the general public that all high-powered sources of energy make a great deal of noise, and that the known effective measures for reducing or isolating the noise in the neighborhood of such a source are much too heavy to be used on aircraft. The only certain method of reduction is more distance between the source and the observer. Both aeronautical engineer and citizen look hopefully to the physicist for new physical principles which might be applied to this problem. Engineers and scientists of the aeronautical industry and government aeronautical agencies are devoting much effort to noise reduction, but the laws of acoustics restrict the possibilities regardless of the effort.

In the United States the principal agency for basic and applied research in aerodynamics, aircraft propulsion, aircraft structures, and aircraft operating problems is the National Advisory Committee for Aeronautics, an independent government agency having close ties with the military services, the aircraft industry, and universities. In Canada there is the sister agency, the Engineering Division of the National Research Council and soon the National Aeronautical Establishment. The relations between the two agencies are very cordial. Continuing advances in aeronautics are greatly dependent on public understanding and support of these important partners of the military services and the aircraft industries in our two countries.